The Bombardment History of Solar System, as Told by Lunar and other Antarctic Meteorites

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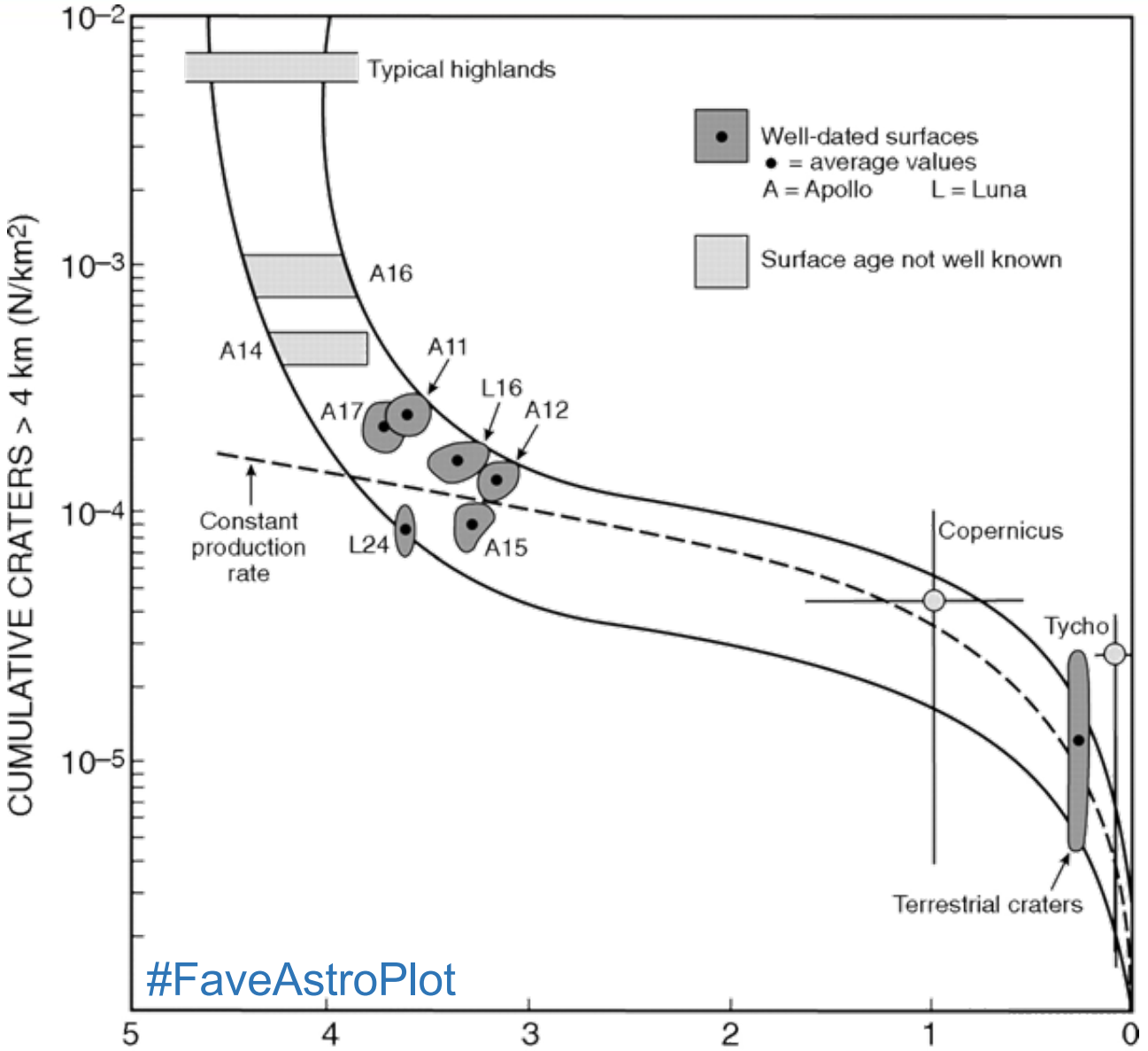
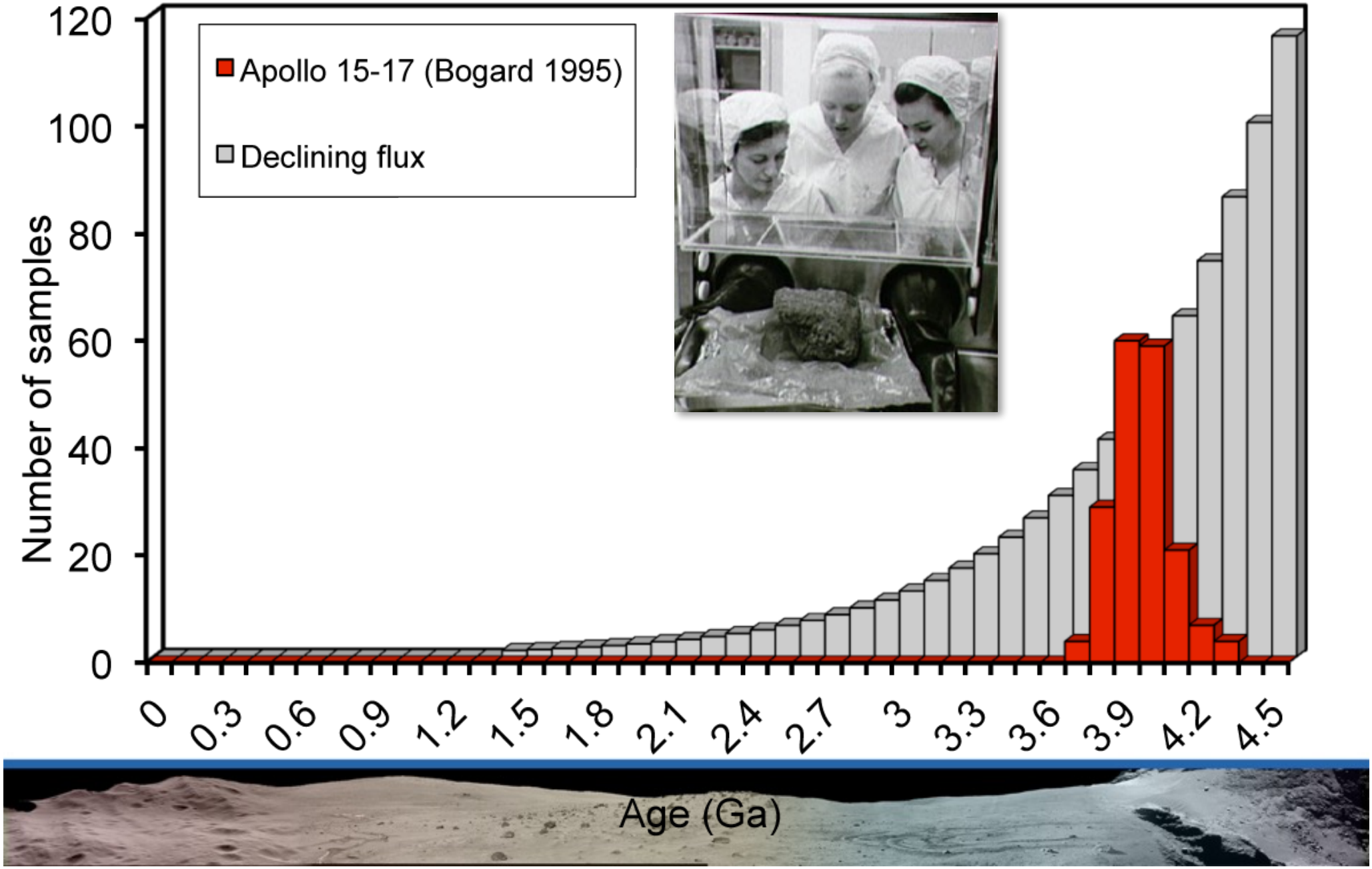
The absolute planetary timescale

- Legacy of the Apollo samples is the link forged between radiometric ages of rocks and relative ages according to stratigraphic relationships and impact crater size-frequency distributions

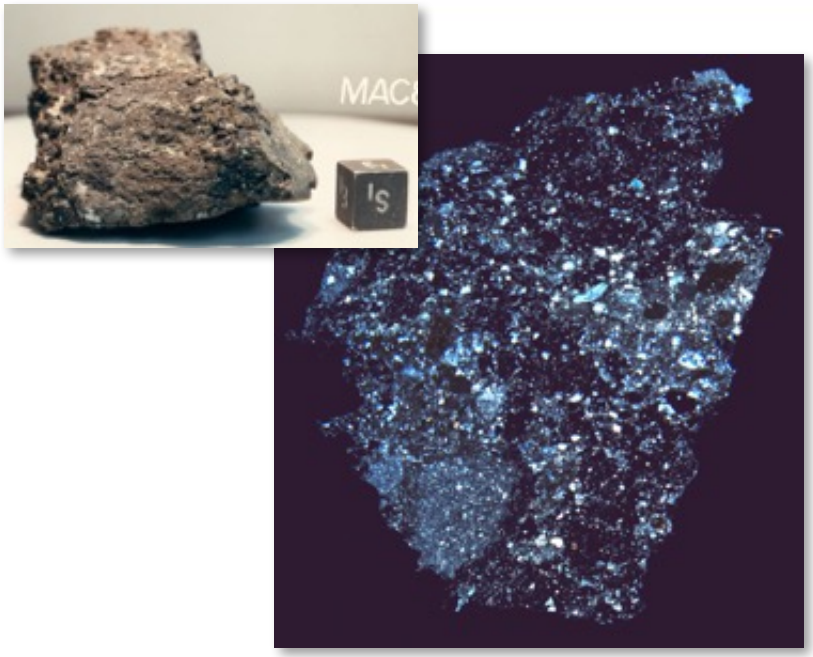


This axis depends on both elapsed time and rate of impacts/time = flux

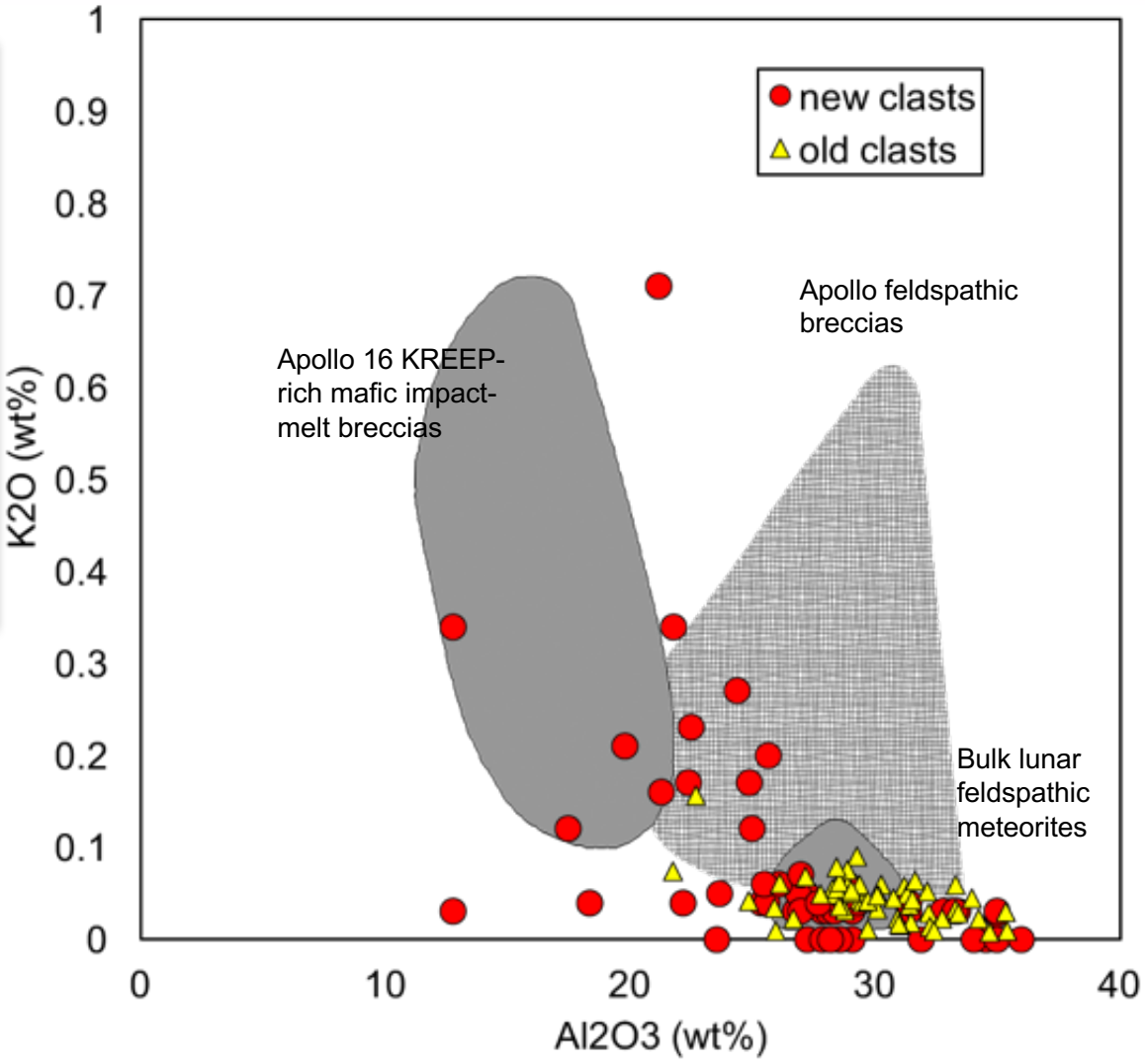
The lunar impact flux (Apollo)



Lunar meteorites



Taylor (1991) examined MAC 88105 clasts and suggested that dating these meteorite clasts would provide a better sampling of impact ages for the entire crust of the Moon



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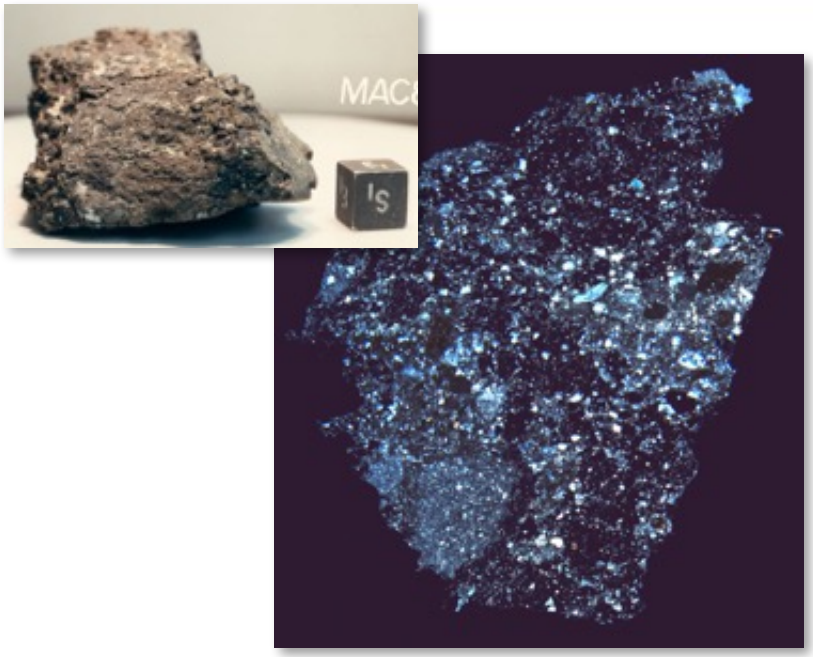

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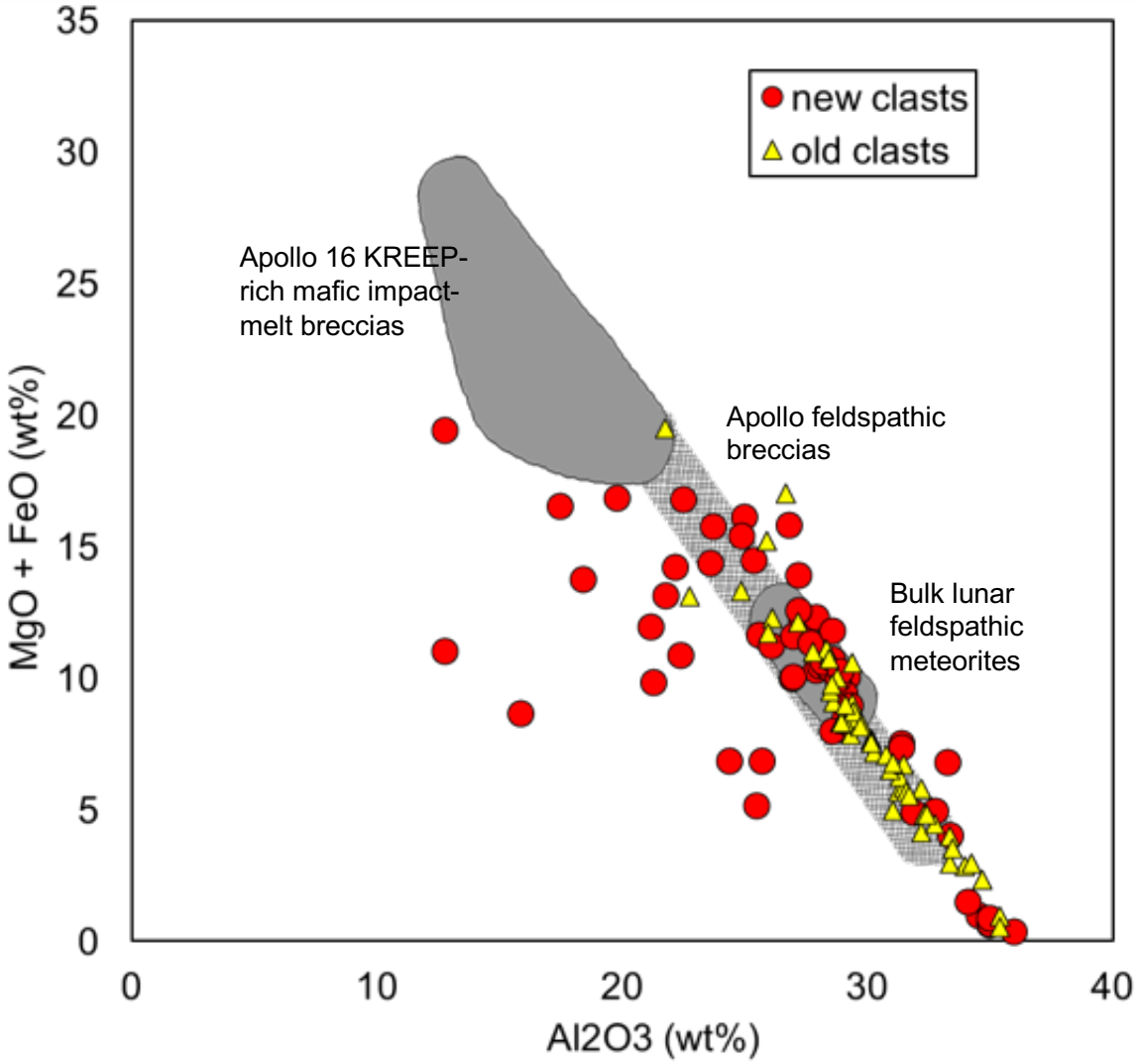
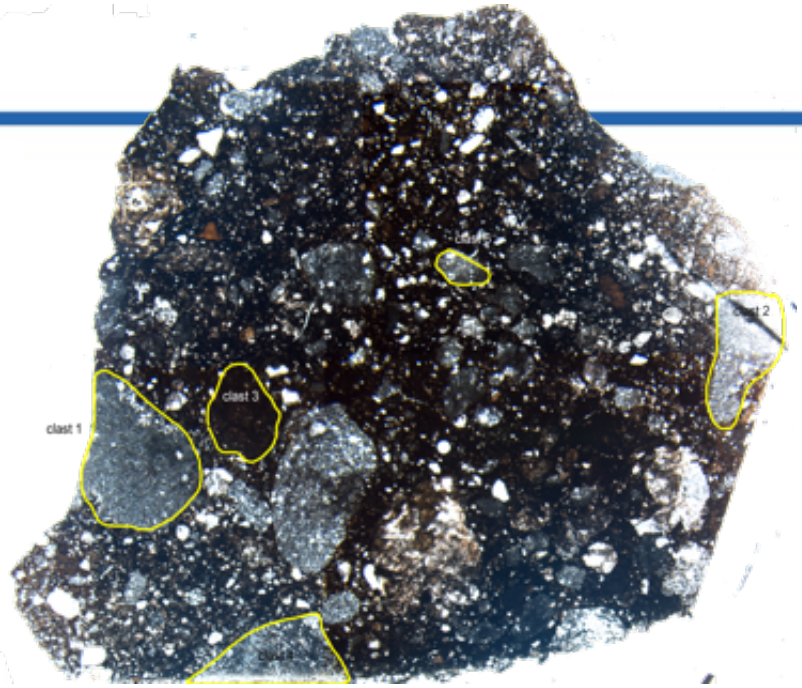
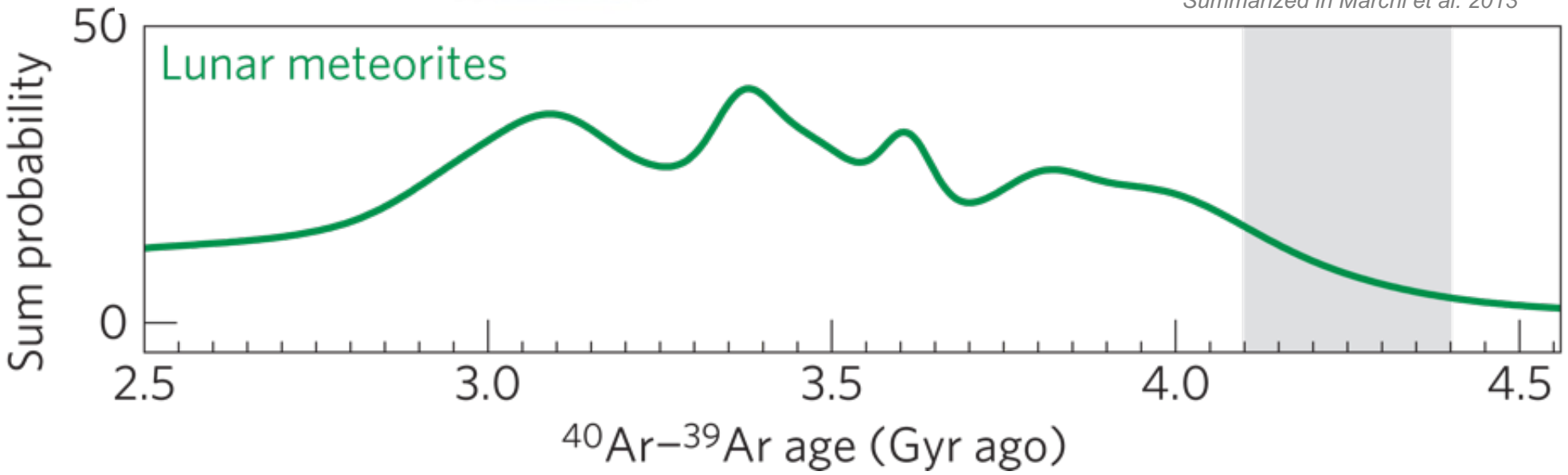


Lunar meteorites

ALHA81005



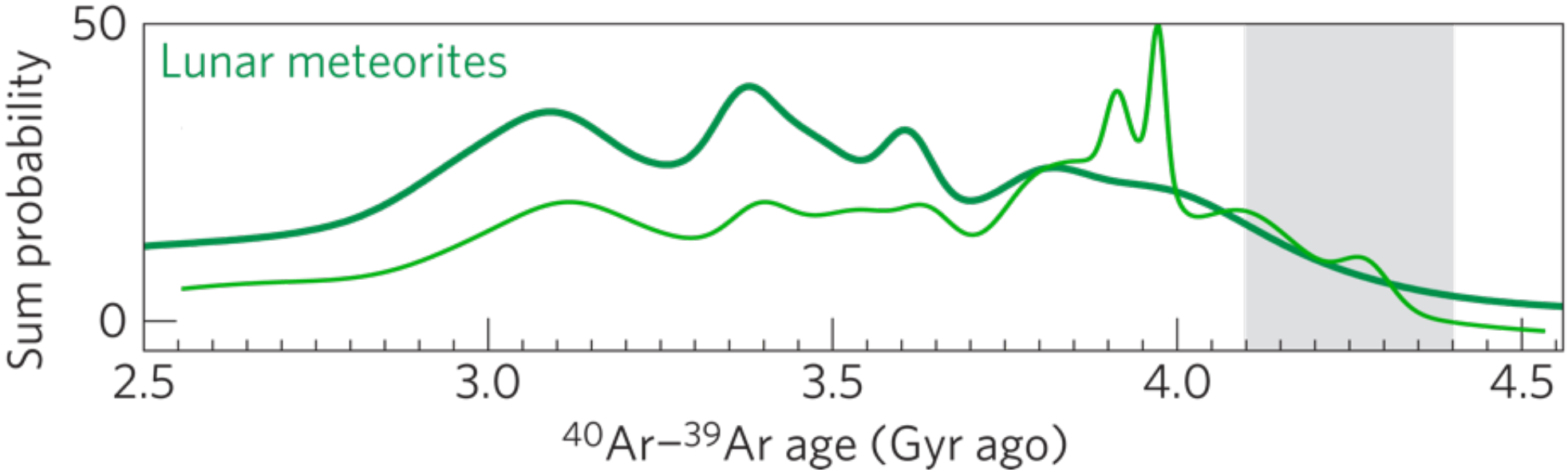
Summarized in Marchi et al. 2013



Lunar meteorites

Updated with:
Impact-melt clasts
Zircons
Phosphates (merrilite, apatite)
Hot-desert meteorites

Arai et al. 2010, Cohen et al. 2000, Cohen et al. 2002, Cohen et al. 2005, Cohen et al. in prep, Fernandes et al. 2000, Fernandes et al. 2004, Fernandes et al. 2009, Gnos et al. 2004, Joy et al. 2011, Joy et al. 2014, Leonteva et al. 2005, Liu et al. 2012, Nyquist et al. 2006, Sokol et al. 2008, Takeda et al. 2006



Lunar meteorites

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Starting to pile up

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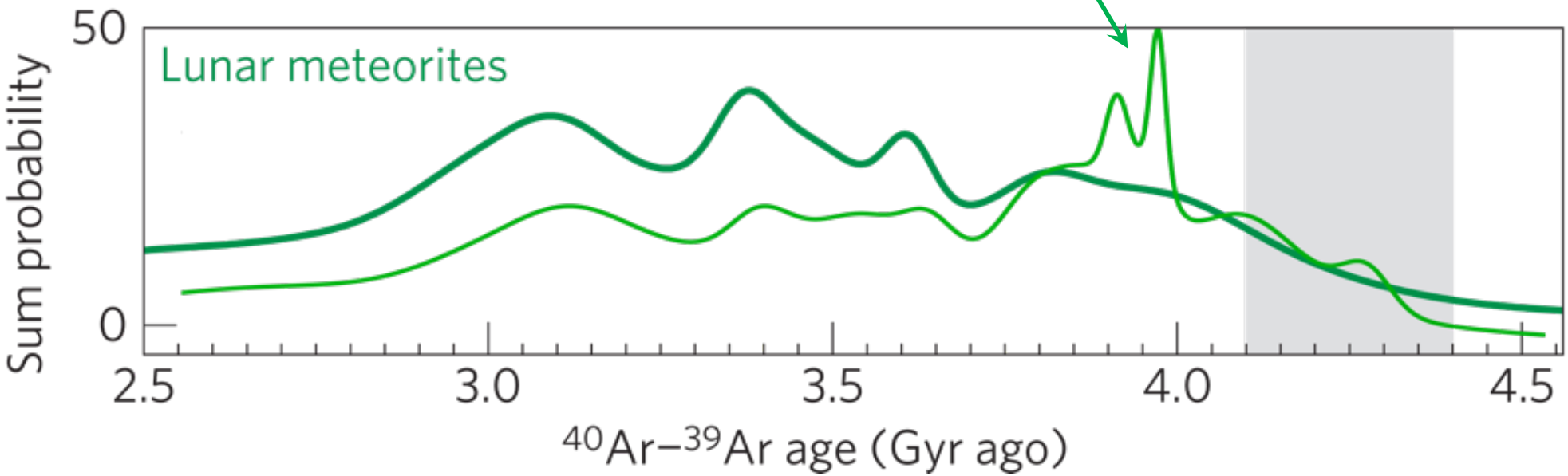

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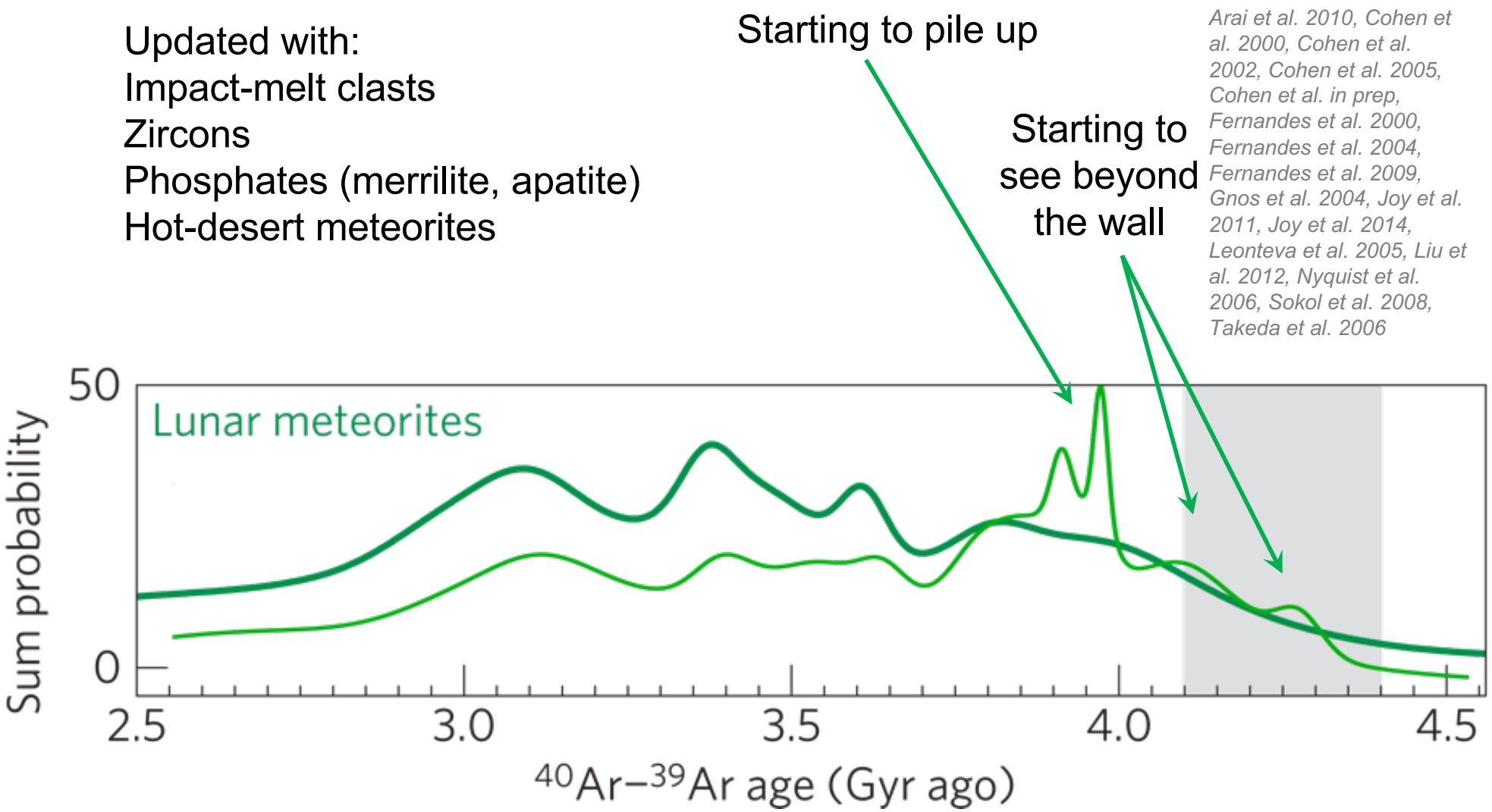
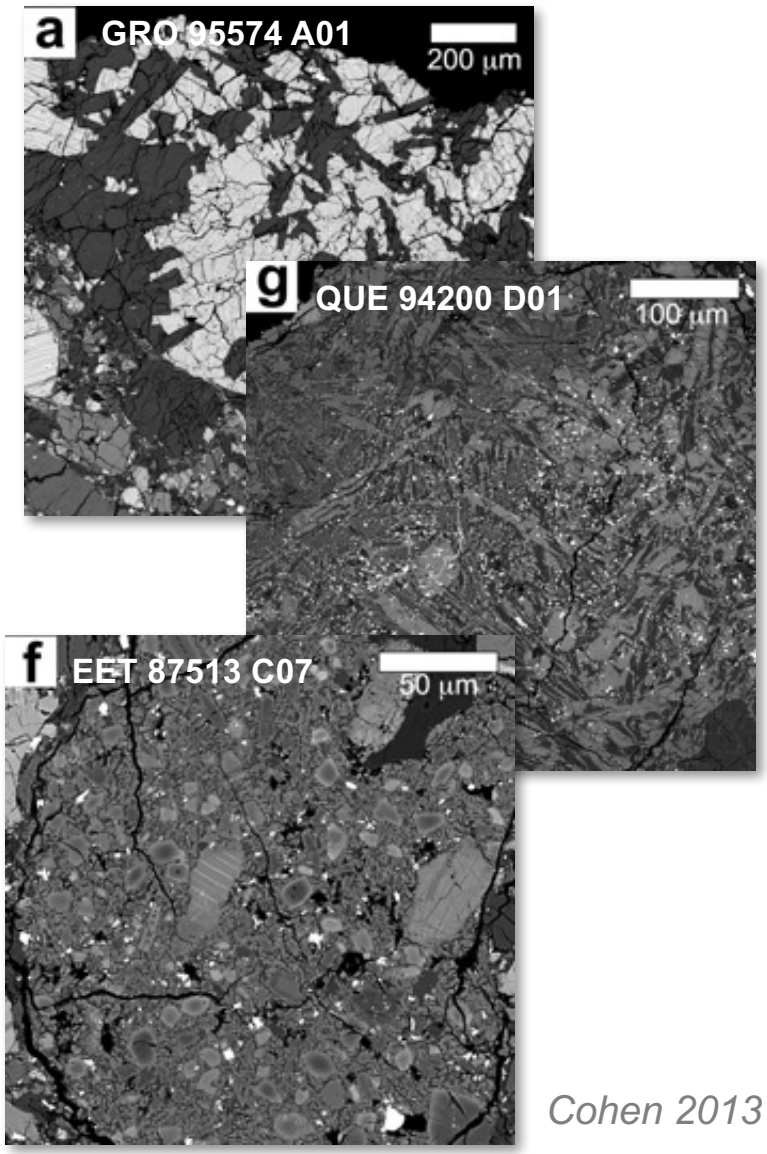
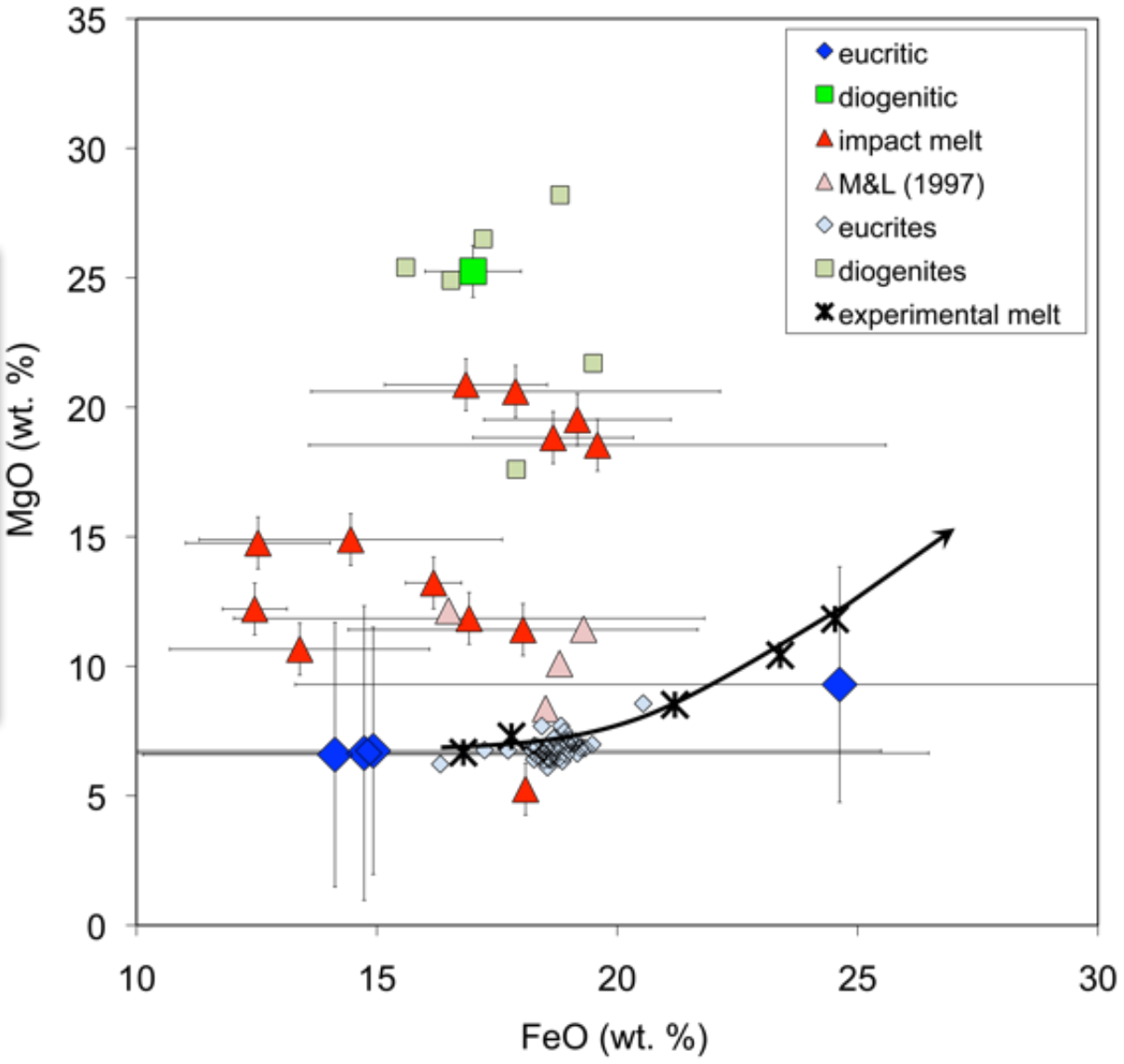


Howardites



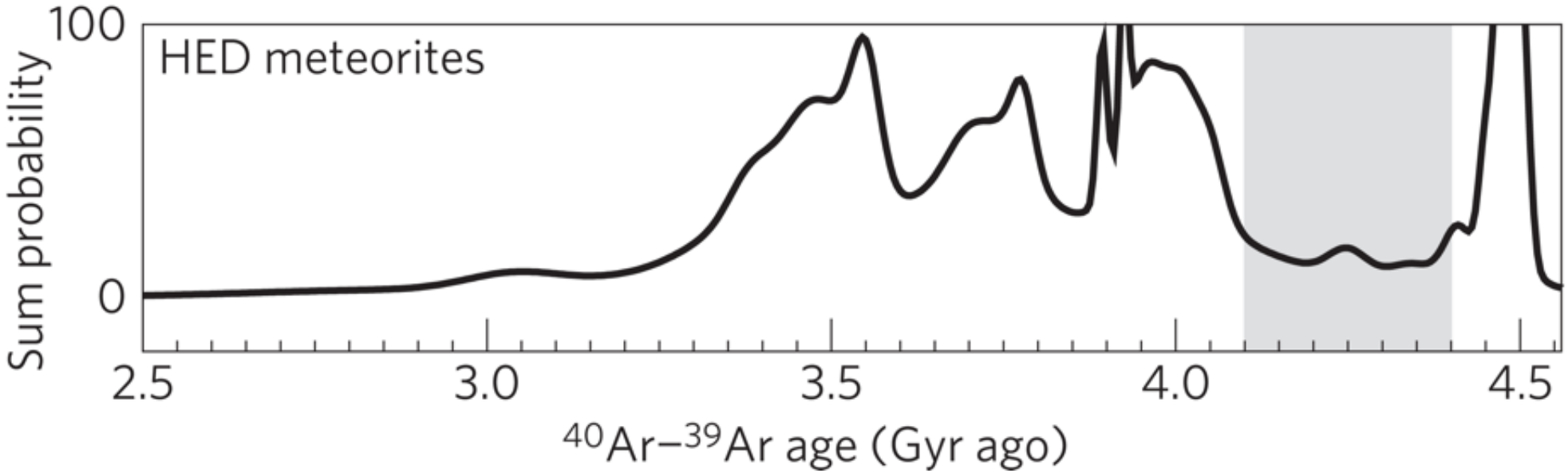


Cohen 2013

Howardites

- New impact-melt ages (11) predominantly 3.6-3.8 Ga
- Forming impact melt on the surface of Vesta well after solar system accretion demands IOUVs (impacts of unusual velocity) – different population of impactors

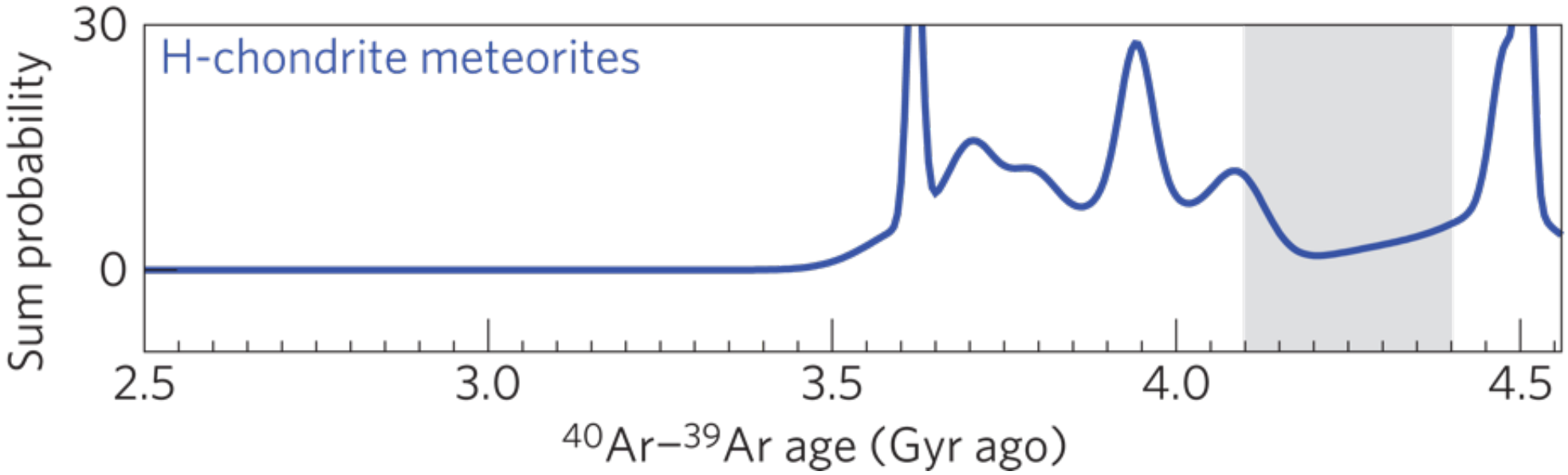
Cohen 2013, Marchi et al. (2013)



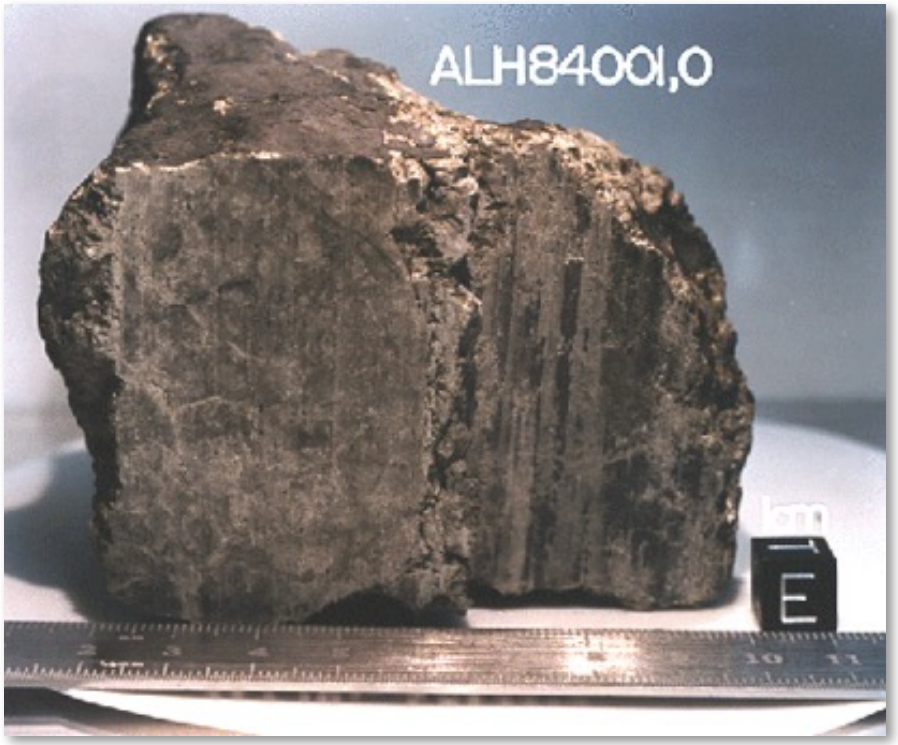
H-Chondrites

- LAP 02240, LAP 03922, LAP 031125, LAP 031173, LAP 031308

Swindle et al. (2009), Marchi et al. (2013)



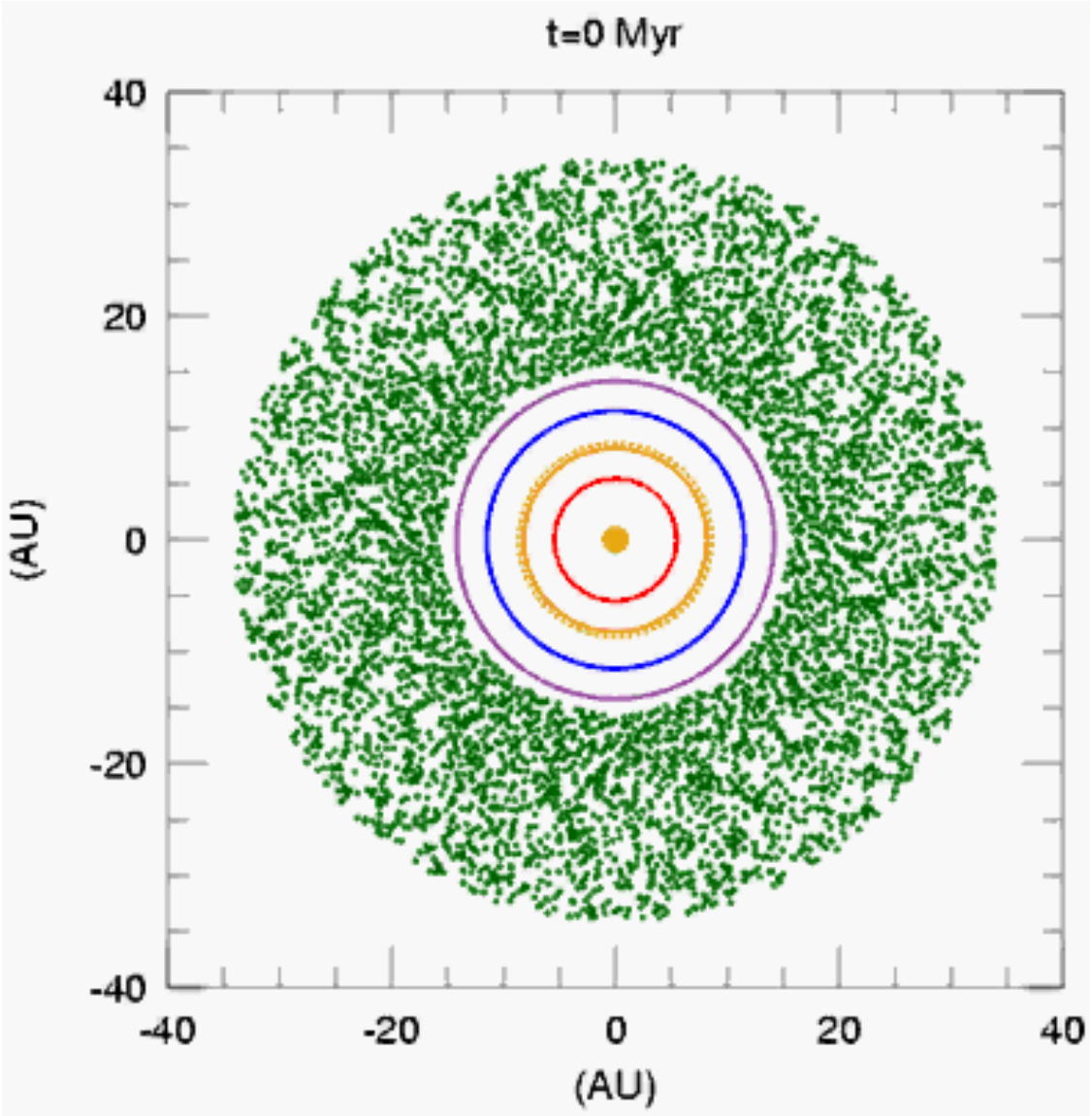
Martians



ALH 84001 (4.51 Ga) has Ar-Ar shock and alteration age of 3.92 Ga

Turner et al. 1997, Ash et al. 1997, Borg et al. 1999

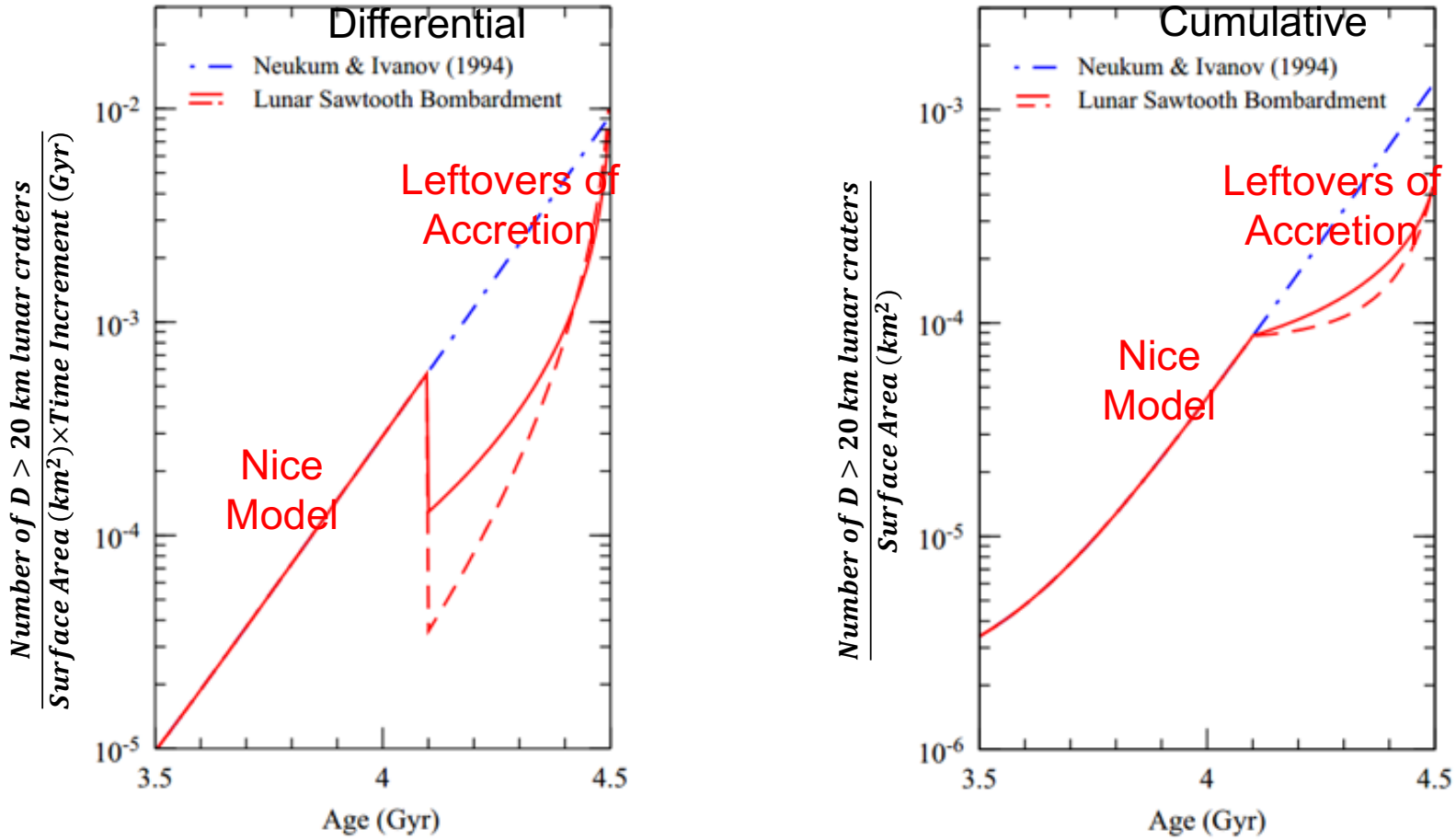
A dynamic early solar system



- Old view: Gas giants/comets formed near present locations (5-30 AU) and reached current orbits ~4.5 Gy ago.
- New view: Gas giants formed in more compact formation between 5 to ~17 AU. Massive comet population existed out to ~30 AU.

Fernandez & Ip (1986); Malholtra (1995); Thommes et al. (1999; 2003); Tsiganis et al. (2005); Brasser et al. (2011); Nesvorny & Morbidelli (2013); Roig & Nesvorny (2014)

Complex populations



- Early: From leftovers of accretion and other debris (< 4.4 Ga).
- Late: From late giant planet migration starting at ~4.1 Ga

Marchi et al. (2012); Morbidelli et al. (2012); Bottke et al. (2012)

Bombardment of solar system(s)

- A post-Apollo view of a dynamic solar system
  - Precise ages of returned *lunar samples** & a large selection of Antarctic & hot desert meteorites
  - Large numerical simulations of planet formation & migration
  - In situ investigation of impact-affected terrains
- Affected the crustal and biospheric evolution of the terrestrial planets and asteroids – Catastrophe? Cauldron? Crucible? Catalyst?
- Extrasolar planet systems!